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THE RELATIONSHIP BETWEEN GAS EXCHANGE AND VOLUME PER MINUTE IN THE HEART FOR BATHS AT VARIOUS TEMPERATURES

Kl. Gollwitzer-Meier

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THE RELATIONSHIP BETWEEN GAS EXCHANGE AND VOLUME PER MINUTE IN THE HEART FOR BATHS AT VARIOUS TEMPERATURES

Kl. Gollwitzer-Meier *

/ 58**

The extent of chemical reactions in the body is a function of the outer temperature. If air is available as an outer conductor, then in humans there is a minimum of energy exchange in a temperature range which extends between 19° and 28° (Gessler [1], Houghton, Teague, Miller and Yant [2] and Grollman [3]). The heat protection of the individual causes the energy exchange to vary considerably. The position of the region of minimum energy conversion varies with the characteristics of the surrounding medium. It is higher if the outer conductor is water, because water has a better heat conductivity and heat capacity than air /59 (Loewy [4]). Kramer [5] carried out investigations at our institute and found that the minimum of chemical reaction activity occurs at 35° for fresh water baths. The blood requirement of the organs changes with the magnitude of consumption. A large blood demand of the organs can be satisfied depending on the overall circulatory system situation by means of increased capillary oxygen exploitation, by deviation of the blood from collateral vessel regions or by increased blood circulation. On the other hand, it is not correct to say that all circulatory system changes

* Balneological Institute of the Hanseatic University of Hamburg at Bad Oeynhausen.

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which occur in a warm bath or in a cold bath are due to the metabolism. The circulatory system situation can change in a bath so much with respect to the nominal condition that clear readjustments of individual circulatory system parameters will occur. According to extended experience of physicians dealing with bath therapy, hydrostatic bath influences are very important in addition to the effects of the bath on the circulation of blood through the skin. A lot of data is available on the volume of blood transmitted through the heart per minute as well as on the overall gas exchange. However, up to the present no one has addressed himself to the question of the importance of the metabolic readjustments and the circulatory readjustments which occur in the bath, and their influence on the overall circulation magnitude. Not enough information is contained in presently available experimental results. This is either because all three heat groups were not investigated using the same test person, or because the volume of blood going through the heart per minute, the gas exchange and the respiration were not given for the same experiment. This is why we had to carry out new experiments ourselves.

Method: The investigations were carried out with the usual basic conditions (sober after lying down for one hour) using healthy test persons (which were used to gas exchange investigations). In order to avoid body movements when entering the bath tub, we used the test device developed by Groedel and Wachter. The test persons laid on a stretcher and were introduced into the bath with a set of pulleys. The stretcher is in a horizontal position while the subject is lying in the water. We do not lower the feet as suggested by Groedel and Wachter when the test persons enter the water, because this must lead to hydrostatic blood relocation and possibly to a slight reduction in the volume per minute. The volume per minute is determined using the acetylene method of Grollman. The oxygen consumption is determined using the gas exchange recorder of Rein. The respiratory volume is determined using a gas indicator. The oxygen consumption is recorded by photography in an adjacent room. The respiratory air is introduced into the room by means of hose connections which are as short as possible. The respiration, volume per minute of the heart, and gas exchange are first measured before the bath and then during the bath, about 5-15 minutes after entering the bath, and finally 10-15 minutes after the bath. The test person is well covered before and after the bath above the water, and laid on the same stretcher as in the bath. The duration of the bath is 10 minutes, a maximum of 20 minutes. The respiratory values are averaged over a time of five minutes.

A. Gas exchange and respiration

The gas exchange in the thermoindifferent fresh water bath (just like in air) has a minimum over quite a broad heat interval. This heat zone, which is metabolically indifferent, does not correspond with the region of thermoreceptor indifference, the subjective thermoindifference sensation in the bath (34-35°). Instead, it exceeds this range to a large and small degree (Figure 1). The position of the minimum of the energy conversion in the bath does not correspond to the basic conversion before the bath, but instead exceeds it (Kramer). We find that the (average) difference is -8%. Since the minimum oxygen consumption and the basic metabolism are identical in a wider heat interval when air is the surrounding medium, we believe that the reduction of the gas exchange in the bath below the basic metabolism value can be brought into correspondence with the complete relaxation of the muscles, to a greater extent than is possible in the bath. /60

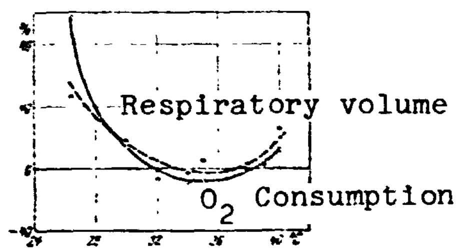

Figure 1. Percentage variation of gas exchange and respiratory volume in fresh water baths at various temperatures.

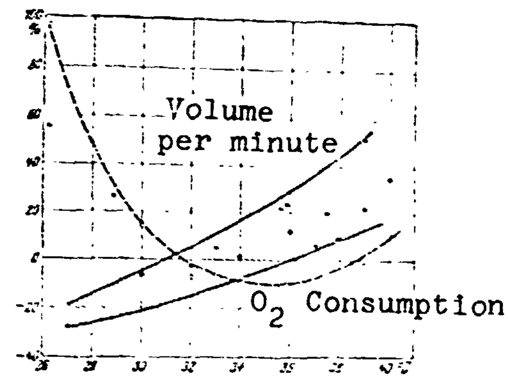

Figure 2. Percentage variations of gas exchange and heart volume per minute in baths at various temperatures. All experimental points taken with the same test person on different days.

Just like the gas exchange, the respiratory volume in the thermoindifferent zone can drop below the initial value 3-10 minutes after introduction into the bath. The small reduction in the respiratory volume, which is not regular, apparently only occurs for sufficient depth of the bath. We must consider the fact that at the time when the subject is introduced into the bath and for the first few minutes thereafter, the respiratory volume is even larger than shortly before this. The subsequent lower value of the respiratory volume only becomes constant after a few minutes. An attempt will be made to establish a correspondence between the drop in the gas exchange and the respiratory volume below the initial value. The respiratory intensity probably drops because the energy metabolism drops. At the present time we are investigating whether any changed sensitivity of the respiratory center is possible in baths with sufficient water depth, in which the hydrostatic pressure effect is substantial and in which the air content of the lungs decreases considerably (Sarre [6]). It is possible that the smaller degree of filling of the lungs with air in the bath and the relaxations of the lungs brought about by this factor will change the sensitivity of the respiratory center. According to investigations of Hess [7], we should expect that the relaxation of the lungs and the reduction in the respiratory central position in the bath would increase the excitability of the respiratory center.

In cold baths, the metabolic behavior varied widely among individuals and also fluctuated for the same test persons on various days to a considerable degree. Our experiments never were carried out at temperatures lower than 26°, because 26° is sensed to be quite cold by a body in the water when the body is completely at rest. Even lower temperatures usually trigger irregular muscle spasms and true muscle motions. The metabolism in a cold bath is higher than in the indifferent zone, even above 26°. The large differences in the gas exchange behavior in cold baths is probably based on the fluctuating occurrence of muscle spasms and muscle stress. The metabolism increase which occurs when the surrounding temperature is reduced has been explained by Loewy [8], Johannssen [9], Sjöström [10], Morgulis [11] by the increase in the muscle activity, and the idea of a chemical heat regulation in the narrower sense is rejected. A chemical heat regulation independent of muscle activity, which occurs via the excitation of the temperature nerves in the skin and via the influencing of the central apparatus, has been put forth by L. Hill [12] and Gessler [13]. Our experiments which show a metabolism increase above 26° even when there are no susceptible muscle spasms seem to support the explanation of Gessler.

In warm baths, the gas exchange increase is a smaller percentage but it is subjected to relatively small fluctuations on the various test days. In 40° baths, the gas exchange values are 10-20% above the basic metabolism on the average (Figure 2). Winternitz [14], Eismayer and Czyrnick [15] have reported higher values. Grollman found smaller increases in the gas exchange in the case where air was the surrounding medium. This is the same thing that we found, even though in a temperature range which was displaced by a corresponding amount. In warm baths the heat of the blood is effective peripherally,as independent of central influences, in addition to the increased respiratory action and heart activity and in addition to the reflecting influences from the skin. The consumptions will therefore increase according to the van't Hoff rule. The changes in the respiratory volume have a completely similar variation as the gas exchange (Figure 1) above and below the thermoindifferent zone.

B. Volume through the heart per minute

The output capacity of the heart remains about the same in thermoindifferent fresh water baths as before the bath. There is a small tendency to an increase (Figure 2). Kroetz and Wachter [16] found an increase in the heart output volume in the indifferent bath on a regular basis in their experiments. According to them, the values are between 13 and 37% above the nominal value before the bath. Our experimental values scatter between -8% to +28%, which is essentially the same range. In our experiments, we found that the heart output volume per minute in the bath was larger than before in most cases.

In warm baths, between 39-40°, we find an increase in the heart output volume per minute of about 20%. Eismayer and

Czyrnick and Lindhard [17] obtained similar results. The data of Bornstein, Budelmann and Rönnel [18] which state that there were increases of 220% in baths at 38.5° using the nitrogen suboxide method cannot be explained by us. Winterstein and Fränkel-Tesman [19] found that the heart output volume per minute is not influenced in a lower heat range, between 36 and 37°. We would like to stress the fact that in a 39-40° warm bath, the increase in the heart output volume per minute usually occurs in humans with healthy vasomotor functions. Only if there are vasomotor disturbances, do we sometimes observe a decrease in the heart output volume per minute and the occurrence of nausea phenomena, already at bath temperatures of 40°.

In cold baths, the output capacity of the heart usually decreases. This decrease amounted to 25% on the average in five experiments. Eismayer and Czyrnick observed decreases of the same order of magnitude. Also this is the case for Bornstein, Budelmann and Rönnel (-10% at 23°). On the other hand, increases in the heart output volume per minute are possible in cold baths, if the muscle spasms are very pronounced. Then the volume per minute increases just like in any other type of body work. For example, this is the case for an experiment shown in Figure 2, in which the volume per minute at 26.6° increases by 55%, and the gas exchange increases by 98% at the same time. However, the heart output volume per minute in cold baths can increase, even for smaller gas exchange increases (because of muscle stresses).

. Relationships between gas exchange and circulatory intensity.

If we relate the changes in the gas exchange and the heart output volume per minute in baths of various temperatures, then we have the relationships shown in Figure 2 for almost all of

the test persons. Figure 2 only shows numerical values obtained for one test person. At temperatures above the thermoreceptor indifference zone, we observed an increase in heart output and gas exchange. The increase in the gas exchange is smaller than the volume per minute. At temperatures which are below the subjective thermoindifferent zone, the volume per minute and the gas exchange vary in opposing directions. The gas exchange increases more than in warm baths, and the volume per minute decreases, except for one experiment with pronounced muscle shivers. The variations in the volume per minute therefore do not follow those of the oxygen consumption. The opposing variation of the heart output volume per minute and of the gas exchange in a cold bath, as well as the comparatively greater increase in the heart output volume per minute in a warm bath (the opposite would be expected if the heart output volume per minute depended on the gas exchange), show that the circulatory readjustments in warm baths and cold baths are not a consequence of the requirements of gas exchange. The gas exchange changes
are so small that the greater oxygen supply to the tissues could /62
be covered without an increase in the heart output volume per minute, by simply exploiting the capillary oxygen to an in-
creased degree. On the other hand, the changes in the heart /63
output volume per minute can easily be explained from the behavior of the circulatory periphery and the exchanges in the cross section of the entire peripheral path under the influence of various bath temperatures. The expansion of the skin vessels, which occurs in warm baths, is not completely equalized by collateral compensation, and the diastolic pressure drops off (Bischoff and Paetsch [20]). The increased vessel cross section means that a compensating increase in the vessel filling, the circulating amount of blood, is necessary. This has been demonstrated in a warm bath and occurs by the rinsing of blood from the blood storage areas. The increased blood flow

back to the heart is expressed by the increase in the heart output volume per minute. Conversely, the decrease in the volume per minute in the cold bath can be understood because of the reduction in size of the peripheral circulatory system due to the contraction of the skin vessels. In the decreased circulatory system, the increased blood requirement of the periphery can be met even with a smaller blood output of the heart. However, if strong muscle motions are triggered in a cold bath, the volume per minute of the heart then increases if the peripheral circulatory system is reduced in size because of the contraction of the blood vessels, just as is the case for any type of body work. On the other hand, the increase in the volume per minute in the thermoreceptor-indifferent bath is not due to the skin vessel effect of the bath, but due to the hydrostatic effect on the flow of blood back to the heart.

SUMMARY

1. If we simultaneously observe the variations in the circulatory system size, total gas exchange and respiration in cold (26-30°), thermoindifferent (34-35°) and in warm (39-40°) baths with the same test person, one observes the same direction and magnitude of these variations.

2. The heart output volume per minute increases from cold baths to thermoreceptor-indifferent and to warm baths. The gas exchange which has increased in the cold bath decreases to a minimum over a wide "metabolic indifferent" heat zone (between 32-38°, instead of 34-35° in the thermoreceptor indifferent zone). This minimum is 8% below the nominal gas exchange (basic metabolism) in air surroundings, on the average. It then again increases in warm baths (39-40°). The respiratory intensity is subjected to about the same changes as the total gas exchange for the three types of baths.

TABLE 1*

FRESH WATER BATHS

Bath temperature °C	O_2 consumption ccm/min.	Heart volume per minute l	Respiratory volume l/min	Remarks
Test person Heb., ♀, 35 years				
26,3	229	3,34	4,7	Before bath
	451	5,19	6,7	During bath
	226	3,24	4,9	After bath
27,2	181	3,94	4,2	Before bath
	209	2,83	3,5	During bath
	185	2,74	3,7	After bath
30,0	183	2,72	4,2	Before bath
	209	2,55	4,9	During bath
	180	2,67	4,3	After bath
30,5	213	2,72	—	Before bath
	200	3,03	—	During bath
	215	2,96	—	After bath
32,1	198	2,80	4,2	Before bath
	185	2,70	4,0	During bath
	191	2,83	4,1	After bath
32,2	204	2,98	4,4	Before bath
	190	2,89	4,3	During bath
	198	3,27	4,5	After bath
34,3	190	2,82	4,2	Before bath
	183	2,88	4,0	During bath
	188	2,77	3,8	After bath
34,9	188	3,25	4,7	Before bath
	173	3,00	5,0	During bath
	167	2,90	4,6	After bath
35,7	238	3,18	4,8	Before bath
	211	3,83	4,6	During bath
	211	2,33	4,5	After bath
35,8	198	3,42	4,8	Before bath
	177	3,00	4,6	During bath
	186	2,96	4,3	After bath
35,8	175	2,26	4,5	Before bath
	155	2,80	5,3	During bath
	164	2,51	4,3	After bath
36,0	176	2,50	5,0	Before bath
	167	2,82	5,3	During bath
	152	2,60	5,1	After bath
36,7	160	2,67	4,5	Before bath
	157	2,61	5,1	During bath
	150	2,35	4,6	After bath
37,0	222	3,13	5,0	Before bath
	219	3,33	4,8	During bath
	221	3,31	4,9	After bath
37,5	185	2,56	4,8	Before bath
	171	3,07	4,5	During bath
	165	2,52	4,6	After bath
37,9	194	3,26	4,7	Before bath
	197	3,57	4,7	During bath
	178	2,70	4,7	After bath
39	196	2,71	4,4	Before bath
	205	4,25	4,5	During bath
39	200	3,[illegible]1	4,5	Before bath
	217	4,05	4,7	During bath
	202	3,11	4,5	After bath
40	198	3,21	4,6	Before bath
	222	4,46	5,4	During bath
	208	2,75	5,0	After bath

* Translator's note: Commas represent decimal points.

TABLE 1 (CONTINUED) *

Bath temperature °C	O_2 consumption ccm/min.	Heart volume per minute l	Respiratory vomume l/min	Remarks	Bath temperature °C	O_2 consumption ccm/min.	Heart volume per minute l	Respiratory volume l/min	Remarks
Test person We., ♂ 28 years					Test person Kr., ♂ 30 years				
27,3	252	2,84	5,8	Before bath	27,5	315	4,48	6,5	Before bath
	308	3,76	6,4	During bath		496	6,20	9,7	During bath
	258	2,97	5,8	After bath		347	5,36	7,1	After bath
27,5	239	2,96	5,8	Before bath	33	321	4,90	7,5	Before bath
	202	2,36	6,6	During bath		297	4,72	7,0	During bath
	243	3.15	5.3	After bath		312	5,10	7,1	After bath
33	312	3.37	5,4	Before bath	34	381	6,10	7,0	Before bath
	285	3.32	5.6	During bath		366	6,95	7,4	During bath
	329	3,32	5,6	After bath		308	4,85	6,9	After bath
39	250	3,35	6,0	Before bath	41,5	349	4,97	8,0	Before bath
	231	3,60	6,0	During bath		395	6,26	9,6	During bath
	256	4,02	6,3	After bath		344	5,85	8,0	After bath
40	245	3,62	5,4	Before bath	42,4	322	4.37	7,0	Before bath
	281	4,54	6,2	During bath		356	6.39	9,0	During bath
	256	3,94	6,3	After bath					

* Translator's note: Commas represent decimal points.

3. The circulatory system magnitude in cold (26-30°) and warm (39-40°) baths is not a function of the metabolism magnitude, but is a function of the overall circulatory conditions. The peculiar influences which occur in the bath on the skin vessel system and its vasomotor functions, as well as the hypostatic influences on the flow of blood back to the heart, play a significant role, just like in the thermo-indifferent bath.

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16. Abstract

The following were measured in cold and warm bath experiments with male and female subjects: gas exchange (O_2 consumption), respiration, volume throughout of heart per unit of time, circulation, metabolism. The findings were interpreted and compared with earlier work.

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